Detector Design and Performance

John Haggerty

Brookhaven National Laboratory

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- **Jets** "Comprehensive and high statistics measurements in jet physics in Au-Au, p/d-Au, and p-p systems at RHIC are an important addition to the mostly triggered jet physics of ATLAS and CMS at the LHC."
- **b-tagged jets** "The proposed sPHENIX program on heavy quark physics, enabled by precise tracking and hermetic calorimetry, will provide important new information, including b-tagged jet physics, where a comparison with the p-A and p-p baseline is particularly important."
- **Upsilons** "High statistics measurements of bottomonium production as a function of transverse momentum and rapidity for p-p, p-A, and Au-Au collisions are particularly important"

"The panel advised that the proposal is an impressive and comprehensive document that demonstrates the importance of the scientific goals and presents a credible preliminary design for a detector that will achieve them."

Design driver: jets

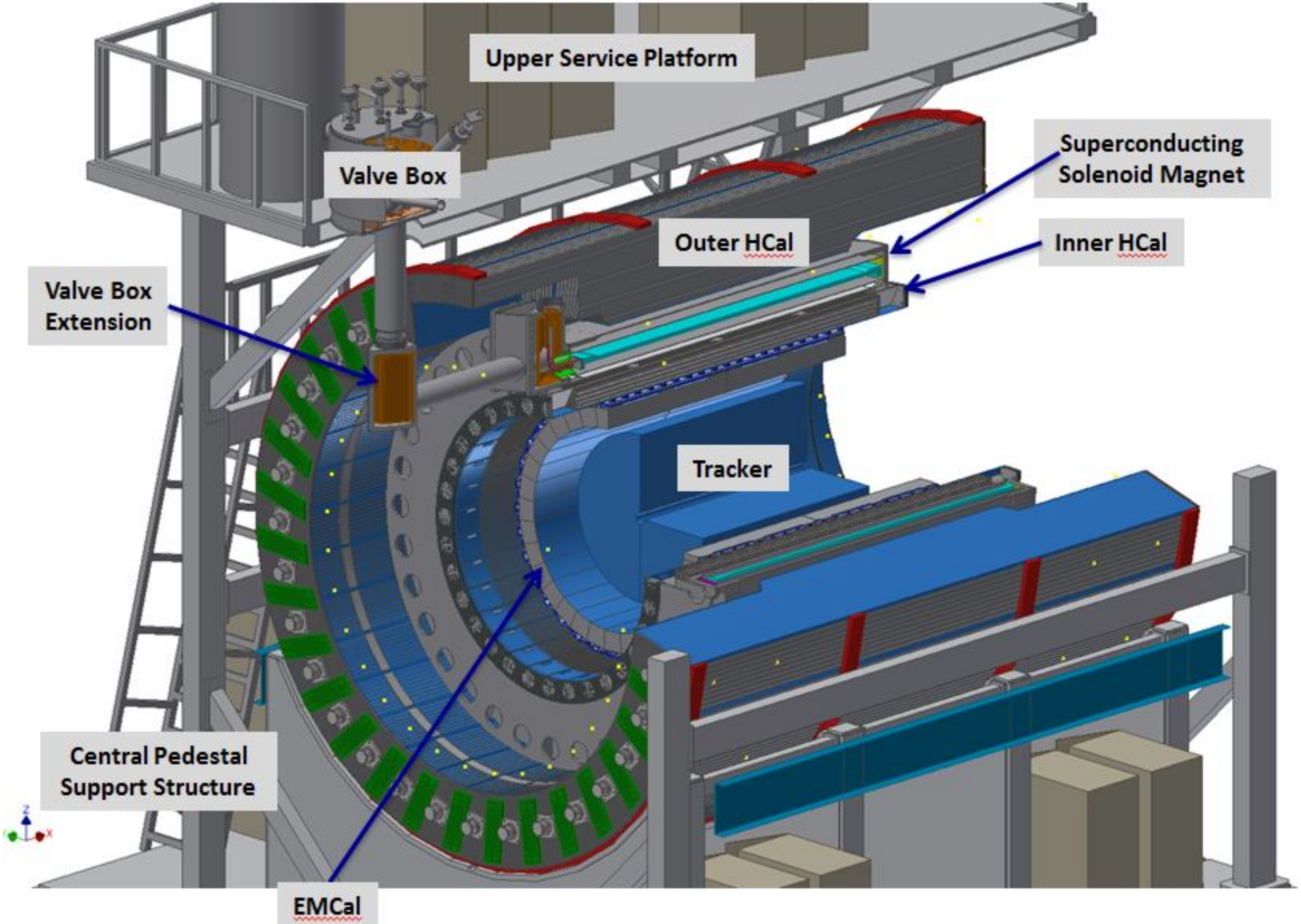
- Jet measurements drove the need for calorimetry, and requires both electromagnetic and hadronic calorimetry to measure the charged and neutral component of both electromagnetic and hadronic showers
- Jets at RHIC
  - Jet energies between 20 and 70 GeV
  - Uniform acceptance without gaps $|\eta|<1$
  - High rates
  - anti-k_T R=0.2, 0.4
  - Unfolding techniques developed for jet identification in heavy ion collisions by ATLAS and CMS

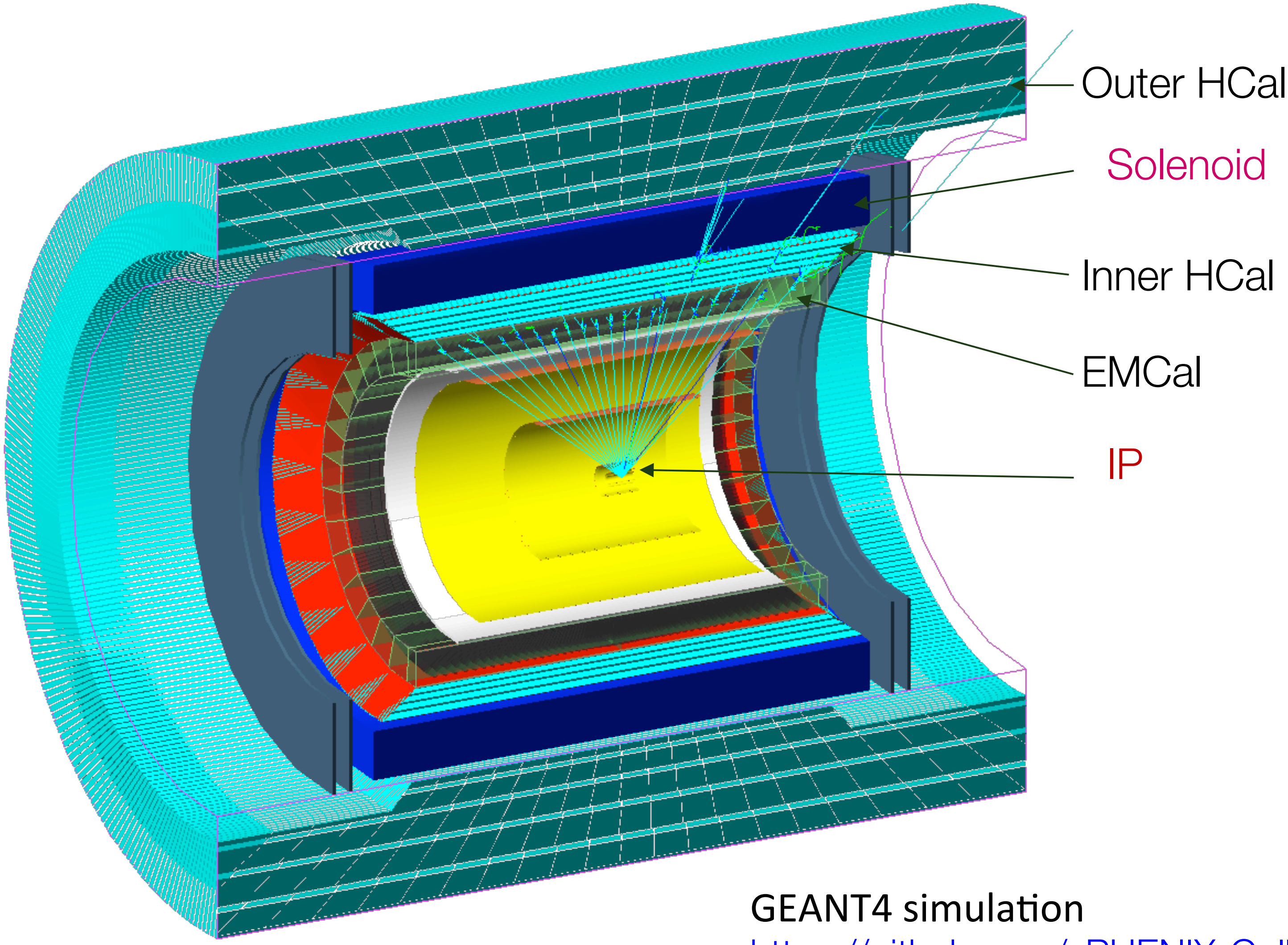
Design driver: tracking

- Separating the Upsilon states cleanly requires a mass resolution of 100 MeV or less
  - Low mass, precision tracking
  - High magnetic field
- Tagging displaced vertices requires Si tracking layers close to the beam pipe
  - Tracking in high multiplicity Au+Au requires small pixel size

The sPHENIX detector concept

- **Uniform acceptance** $|\eta|<1.1$ and $0<\phi<2\pi$
- **Superconducting solenoid** enabling high resolution tracking
- Compact **electromagnetic calorimeter** allowing fine segmentation at a small radius
- **Hadronic calorimeter** doubling as flux return
- **Solid state photodetectors** that work in a magnetic field, have low cost, do not require high voltage, are physically small
- **Common readout electronics** in the calorimeters
- **15 kHz recorded** in A+A allows for large unbiased data sample
- Utilization of infrastructure in an **existing experimental hall** (cranes, rails, beam pipe, power, network…)


Upper Service Platform
Valve Box
Superconducting Solenoid Magnet
Outer HCal
Inner HCal
Valve Box Extension
Tracker
Central Pedestal Support Structure
EMCal



GEANT4 simulation
https://github.com/sPHENIX-Collaboration

BaBar superconducting solenoid

MAGNET

BaBar solenoid

- BaBar magnet secured from SLAC after SuperB canceled, arrived at BNL in February 2015
- Considerable additional equipment also acquired (power supplies, dump resistor, quench protection, cryogenic equipment)
- SMD and CAD preparing it for low power cold test
- Well suited to our needs without compromises
  - 1.5 T central field
  - 2.8 m diameter bore
  - 3.8 m long
  - $1.4X_0$ coil+cryostat

Electromagnetic and Hadronic Calorimeters

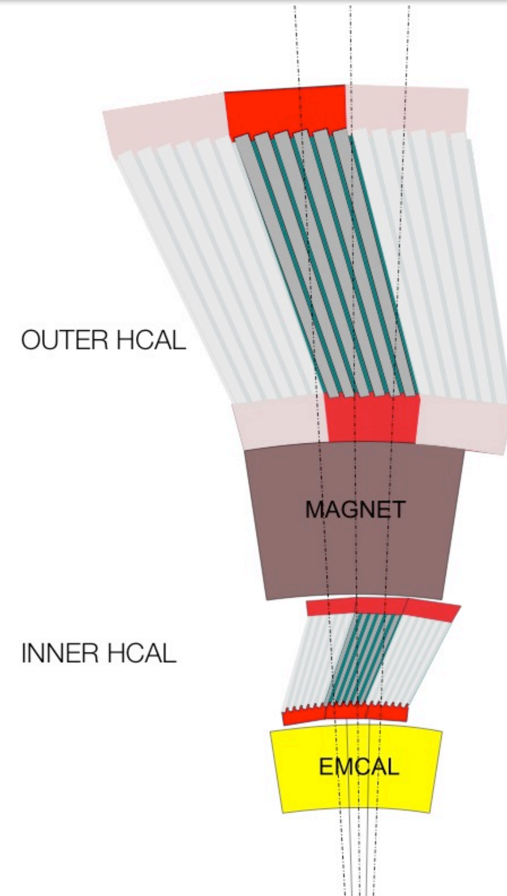
CALORIMETRY

Calorimetry requirements

- Large enough to cover $|\eta| < 1.1$ and 2π in ϕ
- Be uniform without gaps in the fiducial region
- Allow fast readout (most PHENIX detectors come back to baseline in 1 beam crossing or 106 ns)
- High segmentation for heavy ion collisions
- Work in the possible presence of a magnetic field
- Provide trigger primitives in p+p
- At $\eta = 1$, the coil and cryostat are 2 radiation lengths, driving EMCAL inside solenoid
- $18X_0$ in the EMCAL to contain EM showers, and at least $5.5\lambda_I$ in the entire calorimeter system to contain 95% of energy up to 70 GeV
- Energy resolution
    - EMCAL < $15\%/\sqrt{E}$ (single particle)
    - HCAL < $100\%/\sqrt{E}$ (single particle)

Calorimeters reference design

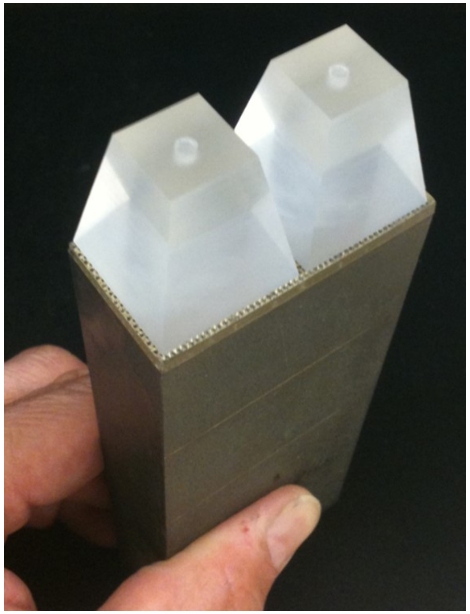
- EMCAL Tungsten-scintillating fiber
  - $\Delta\eta \times \Delta\phi \approx 0.025 \times 0.025$
  - 96 x 256 readout channels
  - EMCal $\sigma_E/E < 15\%/\sqrt{E}$ (single particle)
- HCAL steel and scintillating tiles with wavelength shifting fiber
  - 2 longitudinal segments.
  - An Inner HCAL inside the solenoid.
  - An Outer HCAL outside the solenoid.
  - $\Delta\eta \times \Delta\phi \approx 0.1 \times 0.1$
  - 2 x 24 x 64 readout channels
  - HCAL $\sigma_E/E < 100\%/\sqrt{E}$ (single particle)
- Readout with solid state photodetectors (silicon photomultipliers)



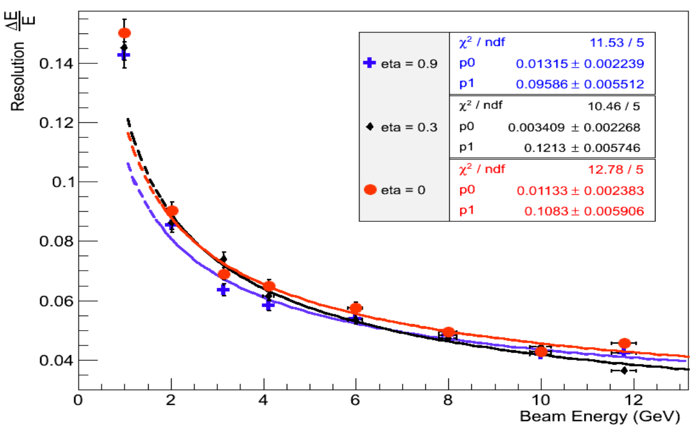
- Outer HCAL $\approx 3.5\lambda_I$
- Magnet $\approx 1.4X_0$
- Inner HCAL $\approx 1\lambda_I$
- EMCAL $\approx 18X_0 \approx 1\lambda_I$

Electromagnetic calorimeter

- Tungsten-scintillating fiber SPACAL
- Radiation length of ≈7 mm allows it to be inside the solenoid where only the material of the tracker is in front of it
- Beam tested by UCLA group
- Development of projective geometry which could improve e/π separation needed for the Upsilon measurements
- Readout on inner radius of EMCAL with 4 3x3 mm SiPM's
- On-detector electronics limited to preamps, bias control and temperature monitoring

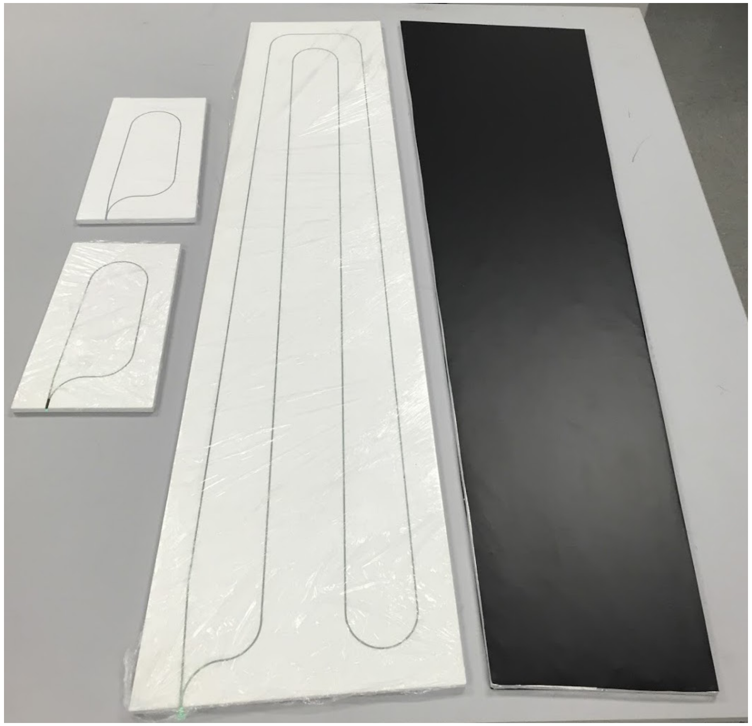


EIC BEMC at eta=0.9, 0.3, 0, Energy Resolution



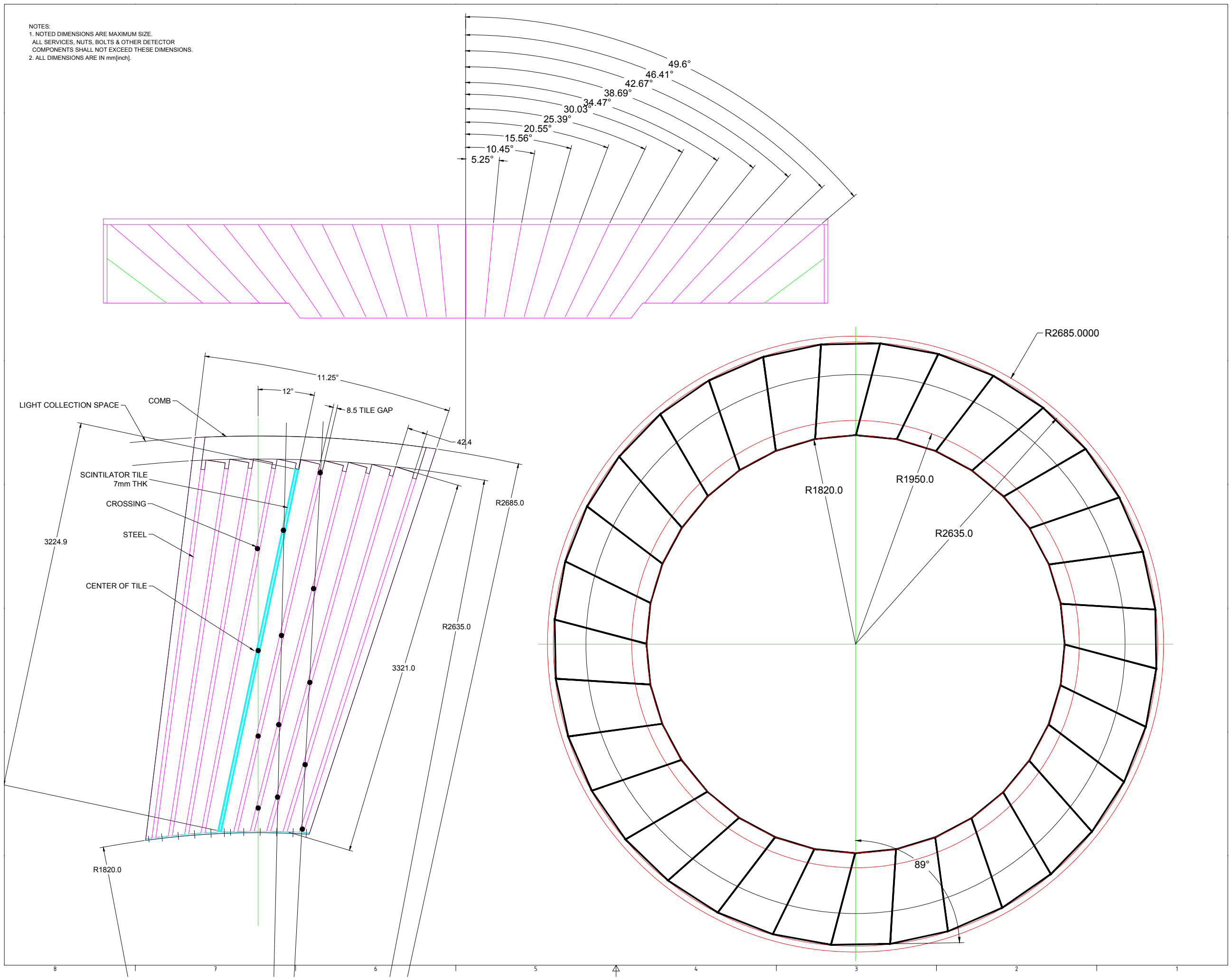
Hadronic calorimeter

- Extruded 7 mm polystyrene scintillator tiles with embedded 1 mm WLS fiber
- SiPM's on the outer radius (one per tile)
- Five tiles in Φ ganged together into tower
- Outer tiles ≈80 cm long
- The outer hadronic calorimeter returns the flux of the magnet



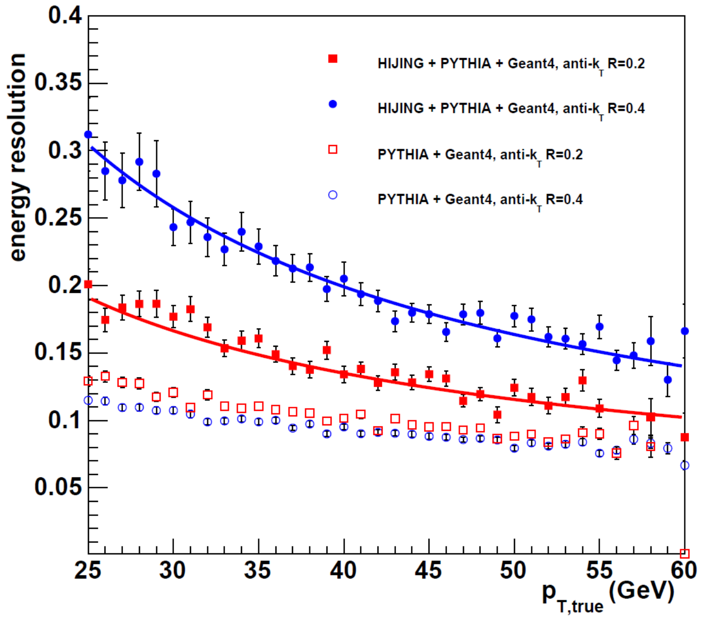
Prototype tiles (Uniplast)

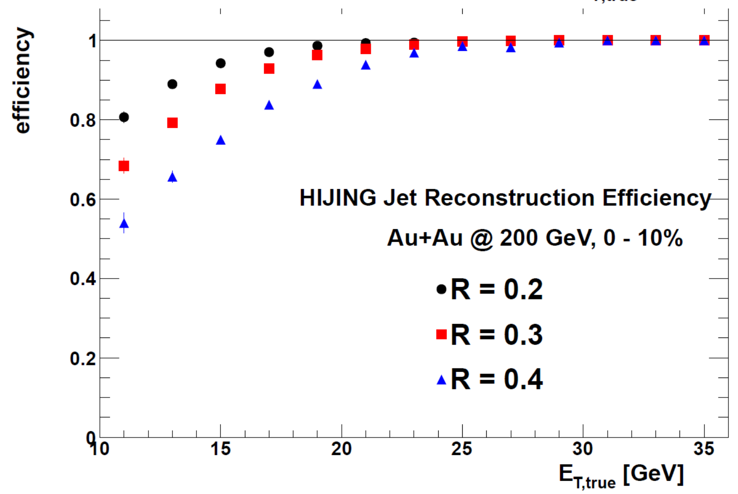
Outer HCAL


NOTES:
1. NOTED DIMENSIONS ARE MAXIMUM SIZE.
ALL SERVICES, NUTS, BOLTS & OTHER DETECTOR COMPONENTS SHALL NOT EXCEED THESE DIMENSIONS.
2. ALL DIMENSIONS ARE IN mm[inch].
49.6°
46.41°
42.67°
38.69°
34.47°
30.03°
25.39°
20.55°
15.56°
10.45°
5.25°
11.25°
12°
8.5 TILE GAP
42.4
LIGHT COLLECTION SPACE
COMB
SCINTILATOR TILE 7mm THK
CROSSING
STEEL
CENTER OF TILE
3224.9
R2685.0
R2635.0
3321.0
R1820.0
R2685.0000
R1820.0
R1950.0
R2635.0
89°

Jets in central Au+Au

- Adapted unfolding procedures developed by ATLAS and CMS to RHIC
- GEANT4 Monte Carlo
- Good efficiency, purity, resolution





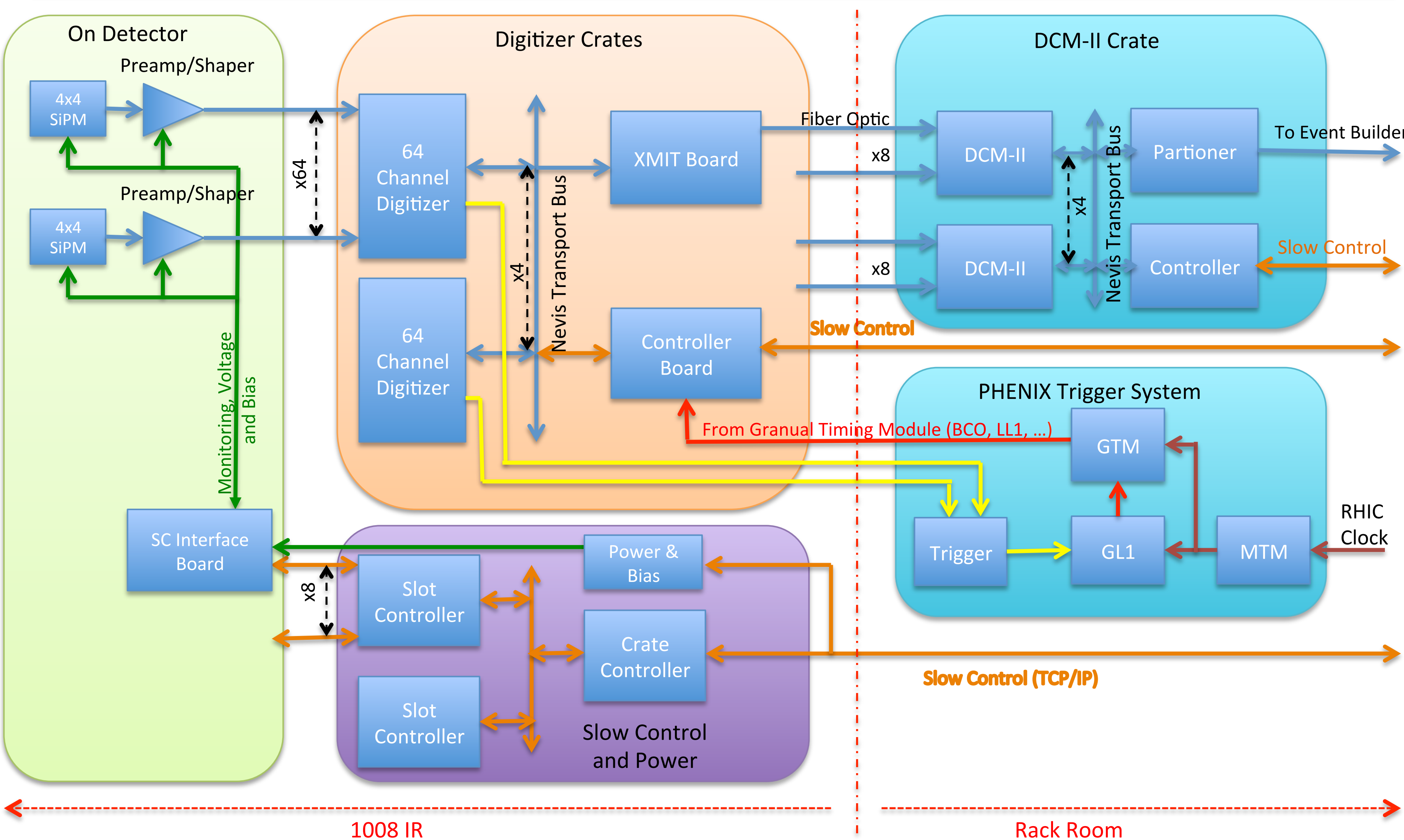
Sensors, preamplifiers, and digitizers (a little about DAQ and trigger)

CALORIMETER ELECTRONICS

Electronics Concept

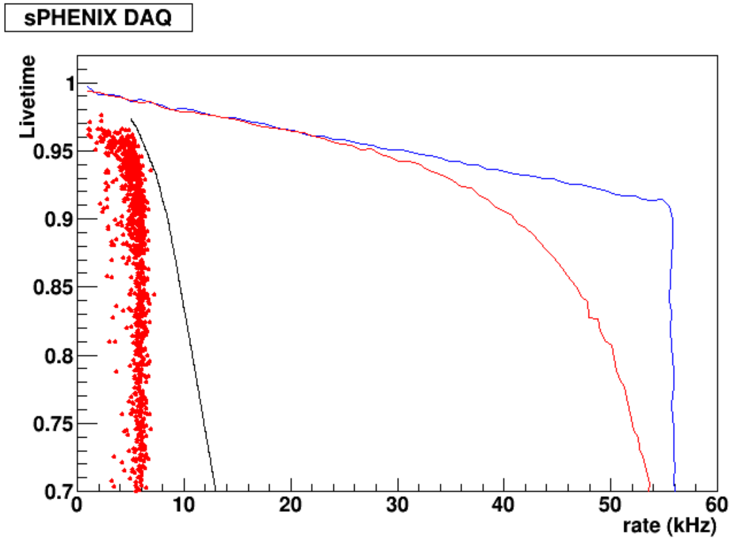
- Based on PHENIX experience
- Maintain as much of the PHENIX DAQ as reasonable
  - Event Builder, DCM-II, GTM, GL1
  - Slow control infrastructure
  - Monitoring and data logging infrastructure
- Similar compact design for EMCAL and HCAL
  - SiPM/tower: EMCAL: 4, HCAL: 5
  - Analog front end on the detector
  - Digitization in the IR, digital data to counting house
- Simple, reliable front end electronics on the detector, minimizing connections
- Commercial components

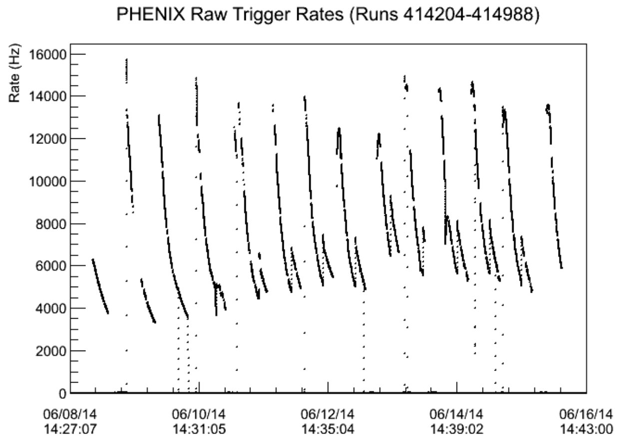
Calorimeter Electronics Overview



Triggering and calibration

- Level 1 triggering
  - Trigger primitives every crossing
  - Level 1 decision in 40 clock ticks (4 μs)
  - Buffer 4 consecutive events
  - 15 kHz accept rate
- Calibration system
  - Pulse injection into front end
  - Light pulser into SiPM's
  - Track gain changes from manufacture through operation





Run 14 Au+Au
(about half of maximum projected)

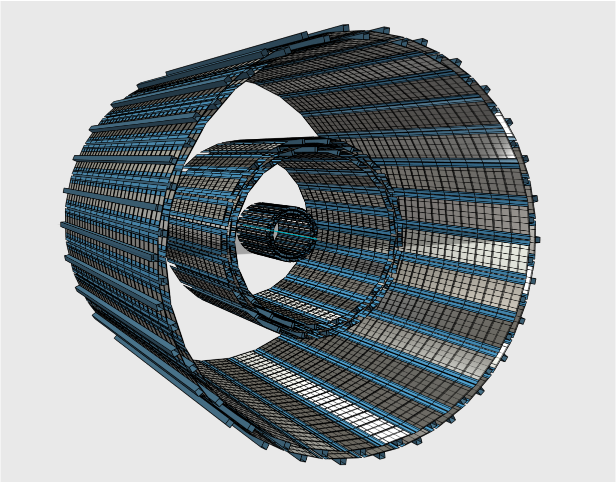
Options for tracking: all silicon or silicon + small TPC

TRACKING

Tracking options compared

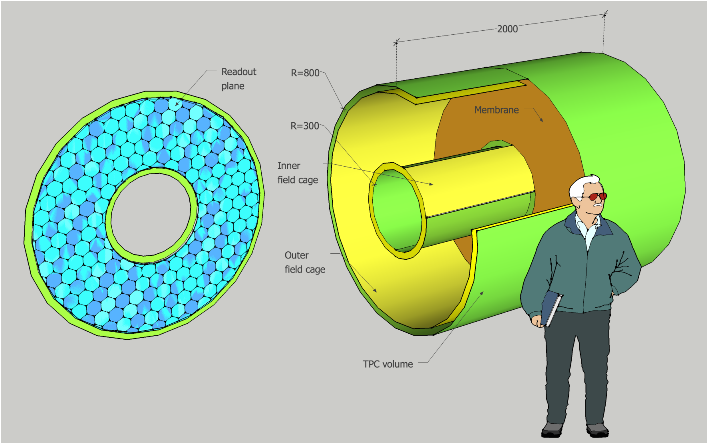
Si tracker

- 7 layers strips and pixels
- Achieves design goals of pattern recognition and 100 MeV mass resolution on Upsilon states
- Total thickness ≈$0.1X_0$

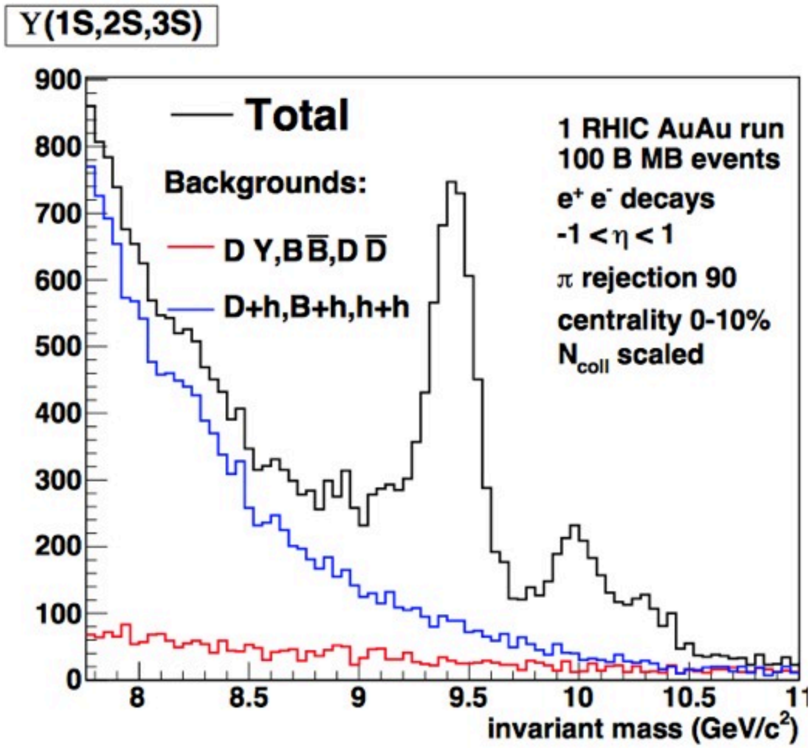


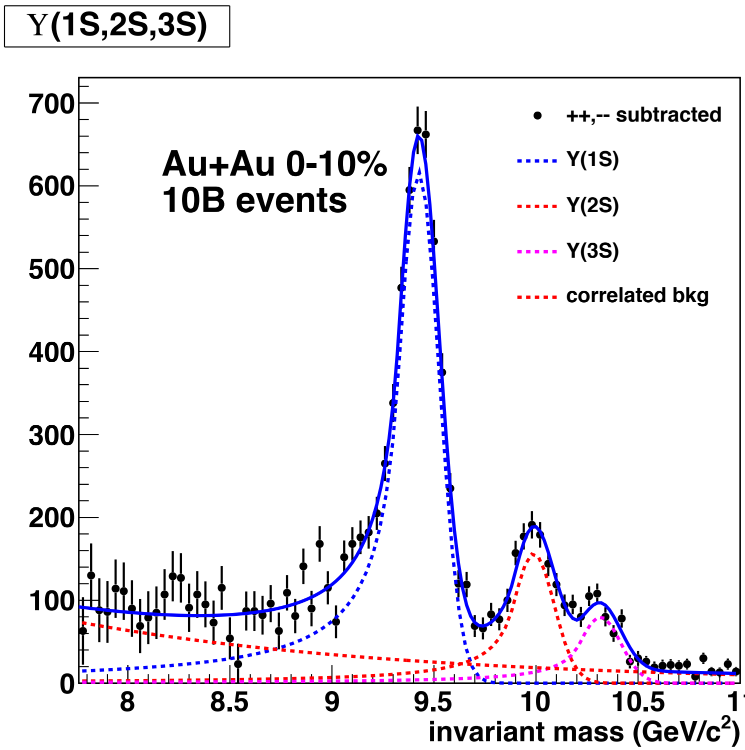
TPC + inner Si layers

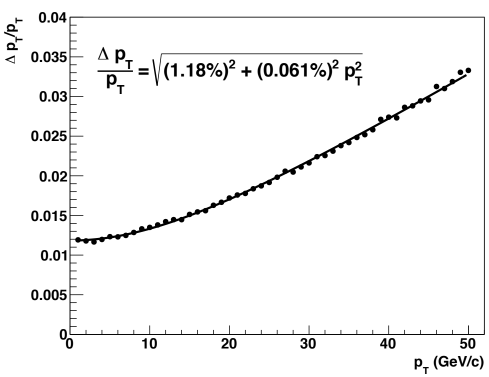
- 80 cm outer radius TPC
- Inner Si detector
- TPC electronics following from ALICE upgrade



Upsilon performance in Au+Au







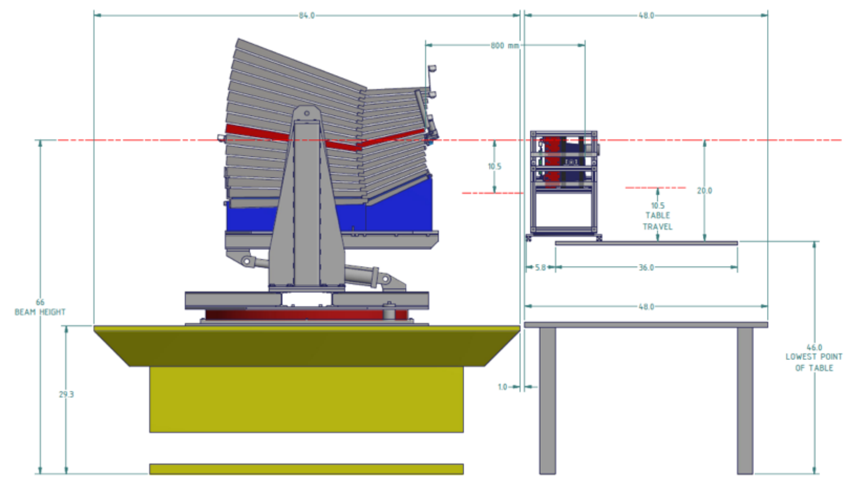
100 MeV mass resolution in reference design

Prototype development and testing, engineering analysis of detector

R&D AND ENGINEERING

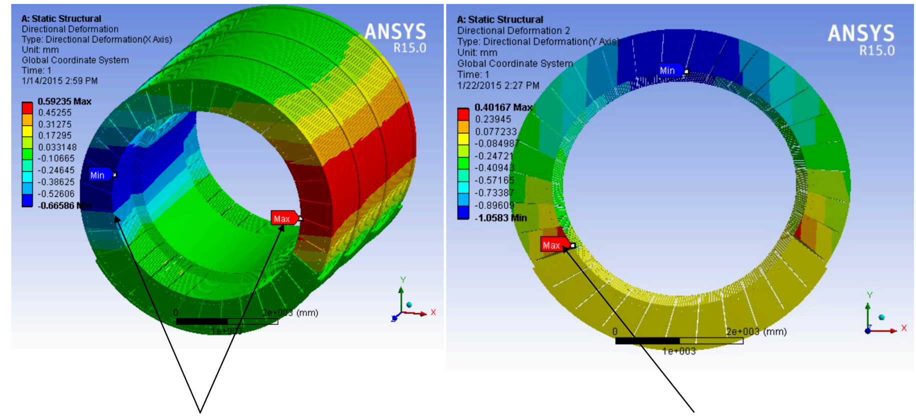
Prototypes

- Calorimeter beam test T-1044 at Fermilab Test Beam Facility
  - February 2014
  - April 2016
- Silicon strip prototypes developed for RIKEN
- Prototype calorimeter electronics at BNL and digitizers developed at Nevis



Engineering

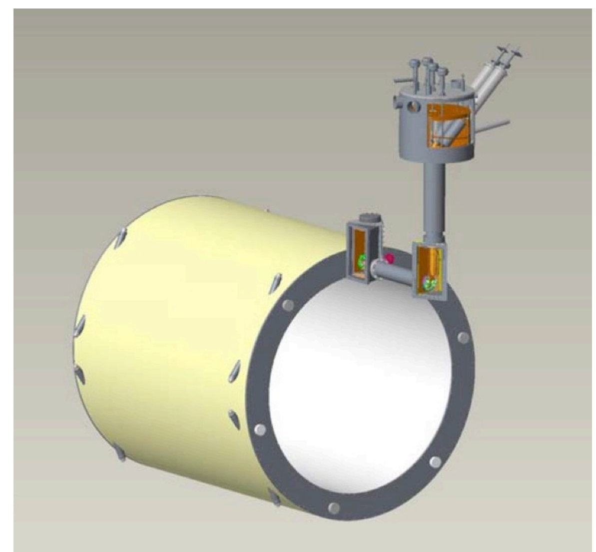
- Structural analyses of assembly
- Magnetic field and force calculations
- Design of cryogenic plant
- Assembly plans and structural analysis



X DEFORMATION +/- 0.6mm

Y DEFORMATION 1mm MAX

FINAL ASSEMBLY DEFORMATION IS WITHIN TOLERANCE



Issues and concerns; summary

CONCLUSION

Issues and concerns

- We want to put our strategy for dealing with SiPM radiation damage to the test
- We need to complete and test our calibration strategy for the calorimeters
- Additional Monte Carlo simulation of the full detector with jets are needed to completely verify the design
  - Including more detailed trigger strategy
- The details of tracking system needs to be elaborated
- We need to focus on the calorimeter beam tests in April and October 2016 and draw conclusions from them expeditiously

Summary

- Although we are still considering ways to improve the design and performance of the calorimeters, the concept is quite mature, has had a first round of prototypes, and plans are proceeding for a second round
- The program of simulation and testing will resolve the open questions in the next year
- The tracking system, with its later start, needs more simulation, engineering, testing, and prototyping, but there are excellent and cost-effective options